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A LARGE SCALE FIELD SHEAR TEST ON A BENTONITE SEAM

by S. T. Thorfinnson, J.M. ASCE

SOIL MECHANICS AND FOUNDATIONS DIVISION

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A LARGE SCALE FIELD SHEAR TEST ON A BENTONITE SEAM

S. T. Thorfinnson,[1] J. M. ASCE

SYNOPSIS

One of the major problems in the design of the outlet works, spillway walls, and the spillway weir at Fort Randall Dam (now under construction on the Missouri River in southeastern South Dakota as an integral part of the Pick-Sloan plan for Missouri Basin development) was the occurrence of numerous relatively weak bentonite and bentonite clay seams in the Niobrara chalk bedrock. This paper describes a large scale field test performed to evaluate the shear strength of these seams. The design of the test, the apparatus used and the test procedure are described and the results presented. The correlation is shown between the results of the field test and laboratory tests made on several of the bentonitic seams.

INTRODUCTION

The outlet works and spillway structures at Fort Randall Dam are founded in Niobrara chalk. The chalk is a sedimentary deposit composed of argillaceous chalk and chalky shale derived chiefly from marine organisms and hardened floculent limey ooze. It occurs in well defined beds varying in thickness from a few inches to a few feet, and is classified as a soft rock. The chalk in itself did not constitute a serious foundation problem; however, numerous bentonitic seams are present throughout the chalk varying in thickness from a maximum of approximately two inches to thin partings. These seams are composed largely of kaolinite and non-crystalline materials with approximately 20-30 percent montmorillonite and small amounts of pyrite and calcite. These relatively weak seams were particularly important in the design of the spillway weir section as it is founded in the upper horizon of the chalk where the greatest concentration of the seams is encountered (see Fig. 1). Data from tests made on bentonite seams on another project indicated that shear strengths obtained from field shear test data tended to be lower than those obtained from laboratory tests. This information raised some doubt concerning the shear strengths that had been adopted at Fort Randall based on laboratory tests. Therefore, a large scale field shear test was undertaken to further evaluate the shear characteristics of the bentonite seams.

Design of the Test

The test was designed to approximate on a very small scale the conditions downstream of a structure founded on chalk containing bentonite or bentonitic clay seams. These conditions are illustrated on Fig. 2(A). The horizontal

1. Civ. Engr. (Soil Mechanics), Omaha Dist., Corps of Engrs., Omaha, Nebr.

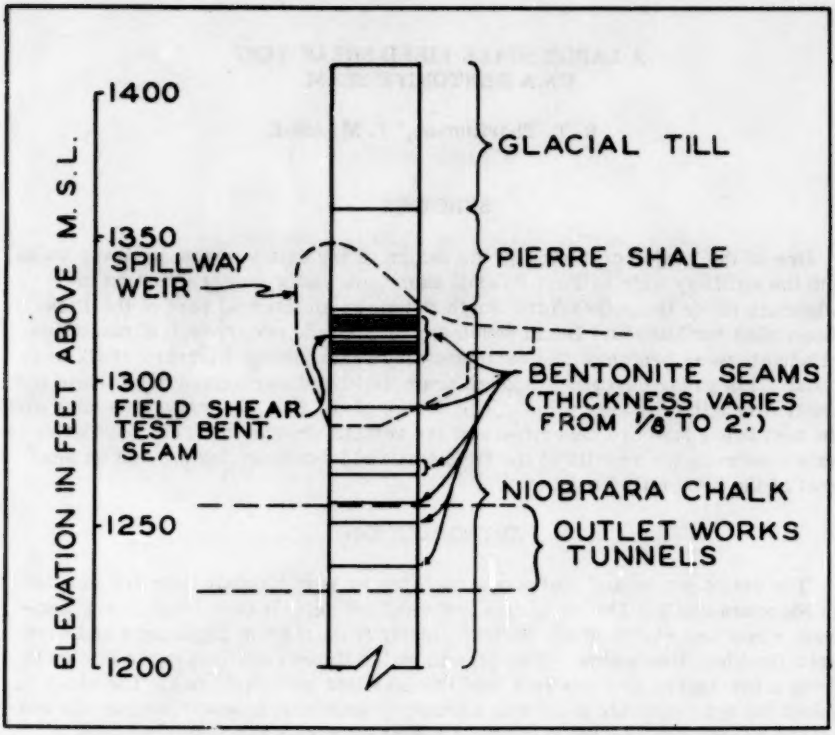
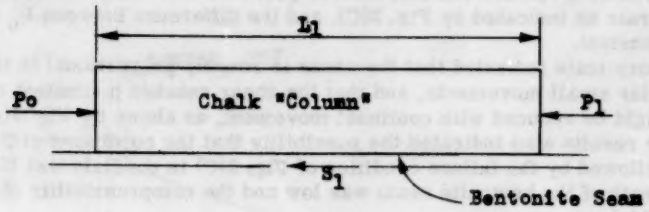


FIGURE 1.
LOG OF TYPICAL BORING IN LEFT ABUTMENT SHOWING BENTONITE SEAMS RELATIVE TO SPILLWAY WEIR SECTION AND OUTLET WORKS TUNNELS.

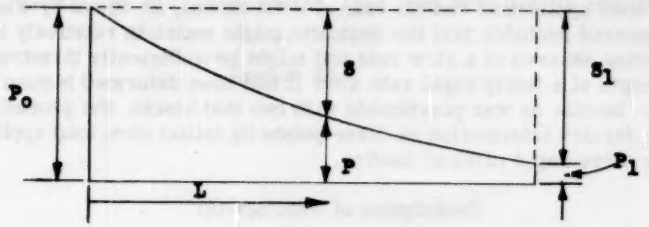
load of the structure, (P_0) is balanced by the sum of the shearing force, (S_1) on the bentonite seam plus a compressive load, (P_1) in the chalk. The differential movement of the bentonite seam is a function of the difference in horizontal loads in successive strata of the chalk. Laboratory tests indicated that, within limits, the shearing stress in the seam is also directly related to the differential movement at the seam. Consequently, the stress-strain characteristics of the chalk in horizontal compression and the shear deformation on the bentonite seams are closely related to one another and to the distribution of shear stress downstream from the structure.

If the shear on a bentonite seam were proportional to the shearing displacement, the theoretical relationship between load, horizontal compression, displacement, and shear would be as indicated by Fig. 2(B). The decrease in compressive load and the increase in total shear would be non-linear, and the load (P_1) would bear a constant ratio to the applied load (P_0). If, on the other hand, the shear on the bentonite seam were independent of the movement, as might



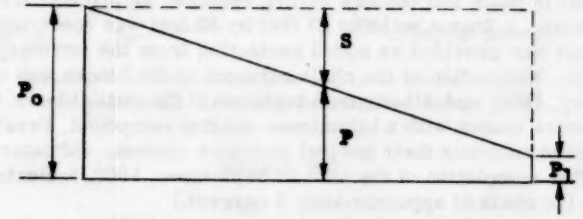
P_o = Structure load (or jack load)
P_1 = Load in chalk column at distance L_1 from loaded end (or transmitted load at rear of test block)
S_1 = Shear on base in interval L_1

(A)



If S is proportional to movement on seam, P_o decreases to P_1, at non-linear rate, and P_1/P_o = constant.

(B)



If S is <u>independent</u> of movement, P decreases at constant rate, and $(P_o - P_1)$ = constant.

(C)

FIG. NO. 2

be the case after large movements, the compressive load would be reduced at a constant rate as indicated by Fig. 2(C), and the difference between P_0 and P_1 would be constant.

Laboratory tests indicated that the shear is roughly proportional to the displacement for small movements, and that the shear reaches a constant maximum or might be reduced with continual movement, as shown by Fig. 3(A). Laboratory results also indicated the possibility that the conditions of Fig. 2(B) might be followed by the failure condition of Fig. 2(C) in the field test if the shear strength of the bentonite seam was low and the compressibility of the chalk was high.

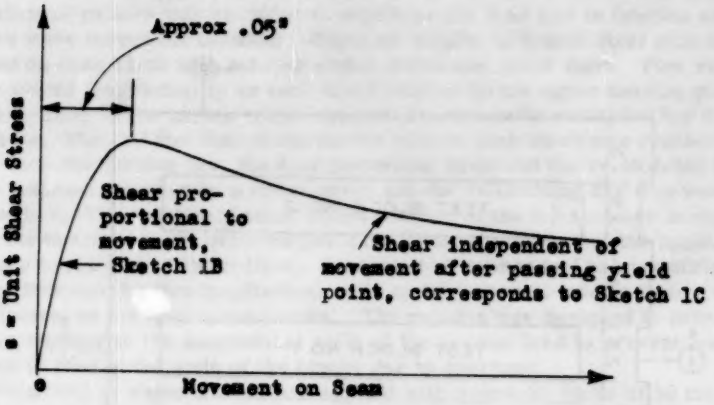
The test set-up was designed to compare the actual conditions with the theoretical limiting conditions illustrated by Fig. 2(B) and 2(C). The loads P_0 and P_1 (hereinafter referred to as the applied load or jack load and the transmitted load respectively) were measured directly, and the variations from P_0 to P_1 were estimated from the deformation of the chalk column, measured by Whittemore strain gages for unit deformation and by dial gages for the total movement with respect to the underlying chalk. The difference between P_0 and P_1 is the total shear, S_1, for the given condition of loading. No direct measurement of the distribution of S could be made, so it was necessary to infer it from the computed rate of change of P, as is explained under "Results."

The laboratory shear strength of bentonite seams varied considerably with the rate of load application and the rate of deformation, as shown by Fig. 3(B). Also, it appeared probable that the bentonite might maintain relatively high strengths when sheared at a slow rate and might be sufficiently thixotropic to regain strength at a fairly rapid rate after it had been deformed beyond the yield point. Insofar as was practicable with two test blocks, the procedure was designed to furnish information on these points by initial slow load application followed by more rapid rates of loading.

Description of Test Set-Up

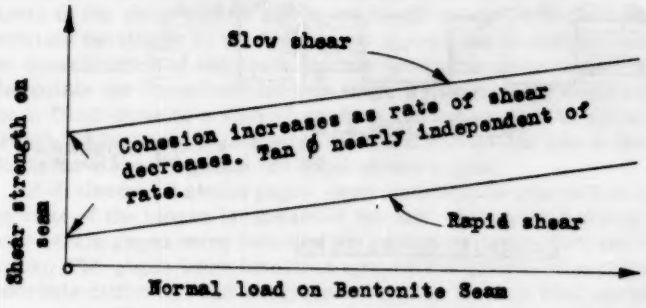
The site chosen for the test was in an area free of contractors' operations, offering access to a bentonitic seam in the same horizon as the spillway crest structure with a minimum of excavation. The surface of the chalk in the location selected was leveled by hand methods and two blocks were laid out in an area free of joints, faults, and zones of broken chalk. The blocks were 18.8 feet in length and 2 ½ feet x 2 ½ feet in cross-section, resting on a bentonitic seam approximately ½ inch in thickness (see Fig. 4). A coal saw was used to cut the outline of the blocks in late November, 1949. The chalk surrounding the blocks was left in place and the saw cutting replaced as protection from freezing and thawing. A frame building 20 feet by 40 feet was constructed over the blocks and heat was provided as added protection from the weather during the winter months. Excavation of the chalk adjacent to the blocks was completed in February, 1950, and all exposed surfaces of the chalk blocks and the bentonitic seam were coated with a bituminous sealing compound, Prestite No. 137, in an attempt to maintain their natural moisture content. (Moisture samples taken after completion of the test, in September, 1950, indicated a moisture loss in the chalk of approximately 5 percent.)

The normal or vertical load on the blocks consisted of 200 tons of railroad rails placed eccentrically resulting in unit loads of 3.0 tons per square foot on block No. 1 and 1.3 tons per square foot on block No. 2 (see Fig. 5). The rails were placed between February and April, 1950, using a traveling hoist. Operations were slowed down due to weather conditions which made mud a


Approx .05"
s = Unit Shear Stress
Shear proportional to movement, Sketch 1B
Shear independent of movement after passing yield point, corresponds to Sketch 1C
0
Movement on Seam

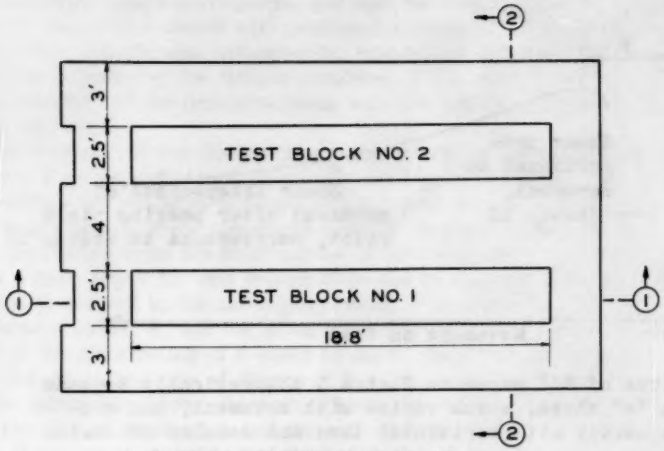
Slope of "S" curve on Sketch 1 theoretically depends on "s" above, which varies with movement, and consequently with horizontal load and modulus of chalk.

Sketch (A)

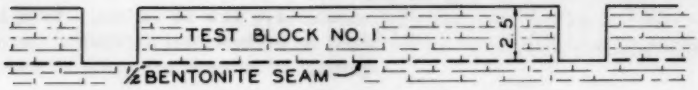

Slow shear
Cohesion increases as rate of shear decreases. Tan ϕ nearly independent of rate.
Rapid shear
Shear strength on seam
Normal load on Bentonite Seam

Sketch (B)

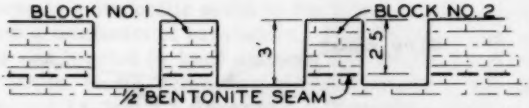
FIG. NO. 3



(A) PLAN OF TEST BLOCKS



(B) PROFILE 1-1



(C) SECTION 2-2

NIOBRARA CHALK

LAYOUT OF BLOCKS

FIGURE NO. 4

major problem. As a safety measure, the normal load was tied to an anchor located outside the pit. This restrained the movement of the normal load so a system of rollers was provided to minimize the load lost in friction as the blocks were moved horizontally. Eighteen lengths of 6-inch steel pipe were placed on each block with bearing plates above and below them. Five rails were placed longitudinally on each block resting on the upper bearing plates and extending to the anchor which consisted of two rails embedded top down in concrete. The end five feet of the center rail on each block was replaced with a 1 ¼ inch reinforcing bar, the four remaining rails and the reinforcing bars were fastened together by a cross piece and the reinforcing bar was welded to the anchor. The relatively small cross-section of the 1 ¼ inch bar made it possible to measure its deformation, thus giving a measure of the applied load lost due to friction of the rollers. A cushion of lumber and celotex strips was placed between the five longitudinal rails and the normal load to insure uniform distribution of the load to the blocks. The cushion was designed to provide proper camber in the longitudinal rails of the normal load to prevent concentration of load at the ends of the blocks due to overhang.

Horizontal or shear loads were applied with hydraulic jacks of 50 ton capacity. In the early phases of the test when the loads were relatively small, one jack was used on each block, operated by Blackhawk P-85 Porto-power units. In later phases of the test when the required loads were much higher, combinations of two and four jacks were used on each block. When more than two jacks were used, the additional jacks were hand-operated, as only two Porto-power units were available. The jacks were blocked up horizontally and centered between two 1 ½ inch steel bearing plates 30 inches square placed against the end of the block and the side of the pit. Uniform bearing was provided by a thin layer of grout placed between the bearing plates and the chalk.

Several types of measuring devices were used in the test set-up, namely, the Whittemore strain gage, the SR-4 electrical strain gage, and dials measuring to 0.0001 inches. Whittemore strain gage points were installed horizontally along both sides of the blocks on two foot centers and horizontally below the bentonitic seam to measure the magnitude and distribution of the compressive strain in the chalk blocks and in the chalk below the seam. They were also installed vertically in the blocks and across the bentonitic seam to measure the consolidation of the chalk and the bentonitic seam under the vertical load. The points for these installations were 2 ½ inch brass wood screws with the heads filed down to a smooth surface and squared up to allow turning with a wrench. Additional points were installed across the gap at the rear of the blocks as a check against the SR-4 strain gages.

SR-4 electrical strain gages were installed on pipe columns and inserted at the rear of the blocks to measure the load transmitted through the blocks. Four strain gages were mounted on each pipe, two active and two compensating gages. The gages were insulated against the effects of moisture; however, considerable difficulty was experienced due to the fact that the pit was at times very damp. Two pipe columns were provided at the rear of each block. Another set of SR-4 gages were installed on the 1 ¼ inch reinforcing bars which were welded to the anchors. These gages measured the load lost due to the friction of the rollers. The SR-4 gages were wired in series to a control switchboard and thence to a Baldwin strain indicator. Precautions were taken to keep the wires leading from the gages to the switchboard as far as possible from the rails to reduce the possible effects due to capacitance.

Dial gages reading to 0.0001 inch were used to measure the relative movement of the blocks along the bentonitic seam. The dials were mounted on short

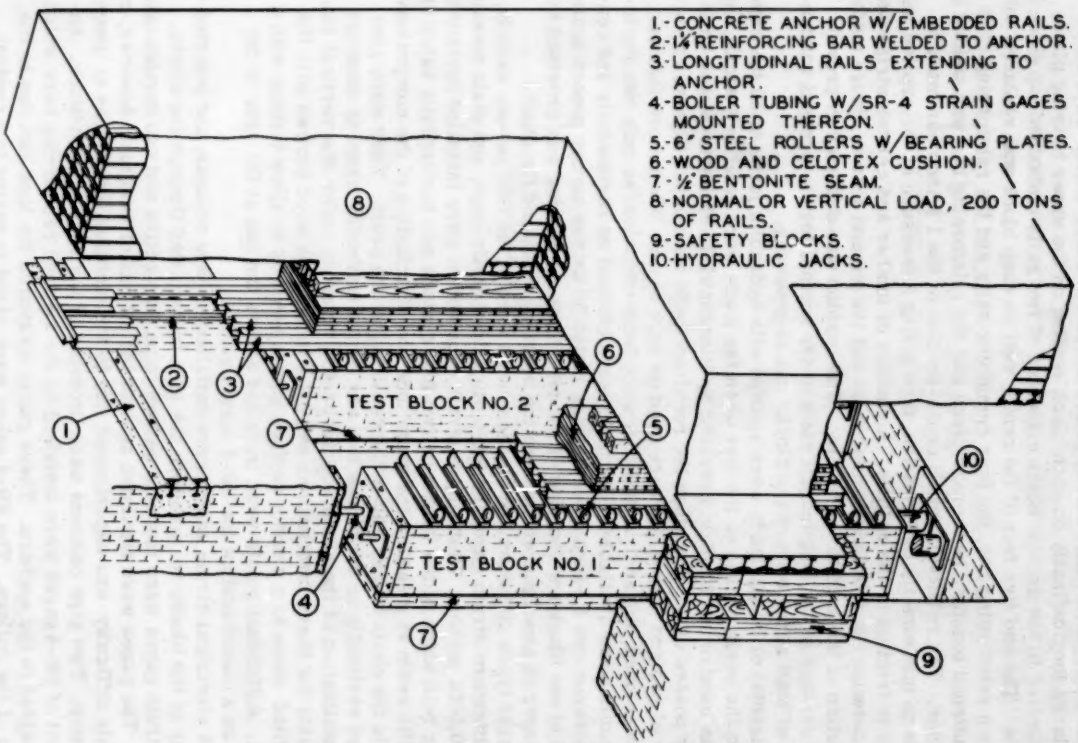

1.-CONCRETE ANCHOR W/EMBEDDED RAILS.
2.-¼" REINFORCING BAR WELDED TO ANCHOR.
3.-LONGITUDINAL RAILS EXTENDING TO ANCHOR.
4.-BOILER TUBING W/SR-4 STRAIN GAGES MOUNTED THEREON.
5.-6" STEEL ROLLERS W/BEARING PLATES.
6.-WOOD AND CELOTEX CUSHION.
7.-½" BENTONITE SEAM.
8.-NORMAL OR VERTICAL LOAD, 200 TONS OF RAILS.
9.-SAFETY BLOCKS.
10.-HYDRAULIC JACKS.
TEST BLOCK NO. 2
TEST BLOCK NO. 1

FIGURE NO. 5 CUTAWAY SKETCH OF TEST SET-UP

lengths of 1-inch pipe grouted into the floor of the pit and reading against steel pins grouted into the sides of the blocks. These dials were mounted on both sides of each block, at the front, middle, and rear of the blocks. Block No. 1 had an additional pair of dials located at the front ¼ point of the block.

Test Procedure

The major differences in procedure for the various parts of the test were in the rate of load application and the magnitude of the loads reached. These were varied to suit the purpose of each phase of the test. The load increments were applied as rapidly as possible and held constant for a period of time before application of the succeeding increment. Early in the test it was found that a period of approximately twenty minutes was required to take a complete set of readings on all the measuring devices. Therefore, throughout the remainder of the test, the time interval between successive load increments was held to some multiple of that period, usually 40 minutes. Generally the blocks were rebounded at the same rate as they were loaded.

The test can be broadly divided into six parts as follows:

1) Part I of the test was intended primarily to obtain data on the stress-strain relationships at loads well below the yield point. Several cycles were run with a maximum horizontal load of 45 kips. Initially the rate of load application was set at 3 kips per 40 minutes, but this rate resulted in loads that were difficult to estimate on the jack dials so it was discarded and most of the remaining cycles were run at a rate of 5 kips per 40 minutes or multiples thereof. The two blocks were loaded simultaneously.

2) Part II of the test was run to obtain information on the shear characteristics of the bentonite seam under slowly applied loads. The major difference between this series and Part I was in the use of higher loads. One cycle was run on both blocks to a load of 95 kips, two cycles on block No. 1 to 100 kips and two cycles on each block to the yield point.

3) Part III was designed to furnish information on the behavior of the bentonite seam under sustained loads. The blocks were allowed to rest approximately 48 hours and then were loaded to a point just below the yield point as determined from part II. Block No. 1 was loaded to 135 kips and block No. 2 to 100 kips. The load was held constant for a period of 10 days and then rebounded to zero. The instruments were read for 3 days after the load was removed. The frequency of readings was reduced to once per 40 minutes during the time the load remained constant as the movements recorded were small. The rate of load application remained at 5 kips per 40 minutes.

4) Part IV was intended primarily to investigate the effect of the rate of load application on the shearing strength of the bentonite seam. Three cycles were run to the yield point on each block. The rate of load application was varied from 5 kips per 40 minutes to 15 kips per 20 minutes on block No. 1 and from 3 kips per 40 minutes to 12 kips per 20 minutes on block No. 2. The first cycle on block No. 2 was made at the same rate of load application as in Part I for comparative purposes.

5) Part V consisted of two cycles to failure, one on each block. Block No. 1 was loaded at the rate of 16 kips per 20 minutes to failure at 272 kips. Block No. 2 was loaded at 8 kips per 20 minutes to failure at 192 kips.

6) Part VI was performed to investigate the thixotropic qualities of the bentonite seam, i.e., its ability to regain strength after failure. The blocks were rested approximately three weeks after the first failure cycle and then failed again at the same rates of load application as were used in Part V.

The test crew was made up basically of five men, one man supervised the test cycle and kept running plots of such information as (1) applied or jack load vs dial movement at the various points along the blocks, and (2) applied load vs time vs transmitted load, i.e., the load measured by the SR-4 gages mounted on the tubes at the rear of the block. Another man took the various SR-4 strain gage readings. Two men, one on either side of the test block, handled the Whittemore strain gages and the dials and one man operated the jacks and handled the portable generator that supplied power for the lighting system. When tests were made simultaneously on both blocks, one man was added to the crew to handle the Whittemore strain gage and the dials on the outside of the second block. The man between the blocks handled the Whittemore strain gage and the dials for both blocks with the assistance of the SR-4 men. On the longer test runs two crews were used on a 12 hour shift basis.

Results

The modulus of the chalk in horizontal compression or compression parallel to the bedding planes was determined for each loading cycle of the test that was made to maximum loads at or below the yield point. The unit compressive strain, as measured by the Whittemore strain gages, was plotted for each of the measuring points along the length of the blocks using the average of the strain measured on the two sides of the block, as illustrated by the typical curves on Fig. 6. The relationship between applied load and transmitted load was obtained for each cycle by plotting the applied load, (P_0), vs the transmitted load, (P_1) as shown on Fig. 7. A strain modulus in terms of unit strain per kip of applied load was determined for each measuring point using a straight line approximation of the strain curves. These strain modulii were then plotted vs the length of the block giving a strain distribution curve as shown on Fig. 8. The curve was extrapolated to the ends of the blocks where the compressive stresses were equal to the applied load and transmitted load at the front and rear of the blocks respectively. The modulus of the chalk in compression was computed for each end of the blocks by dividing the unit stress by the unit strain as illustrated on Fig. 8. Generally, the modulii computed at the front and rear of the blocks for each cycle checked very closely, indicating that the modulus was constant throughout the length of the blocks.

The values obtained ranged from a maximum of 375,000 psi to a minimum of 198,500 psi with an average value of 288,000 psi. These values compare favorably with results from laboratory tests on horizontal specimens of chalk from Fort Randall Dam and on specimens from the Harlan County project (see Table 1).

TABLE 1

Project	Type of Test	No. of	Modulus of Deformation in Horizontal Compression in psi		
			Max.	Min.	Avg.
Ft. Randall	Field Shear	19*	375,000	198,500	288,000
Ft. Randall	Laboratory	10	380,000	148,000	235,400
Ft. Randall	Dynamic Mod.	—	—	—	300,000
Harlan Co.	Laboratory	9	333,000	182,000	259,000

*Note: Nineteen cycles of the field shear test were used in computing these values.

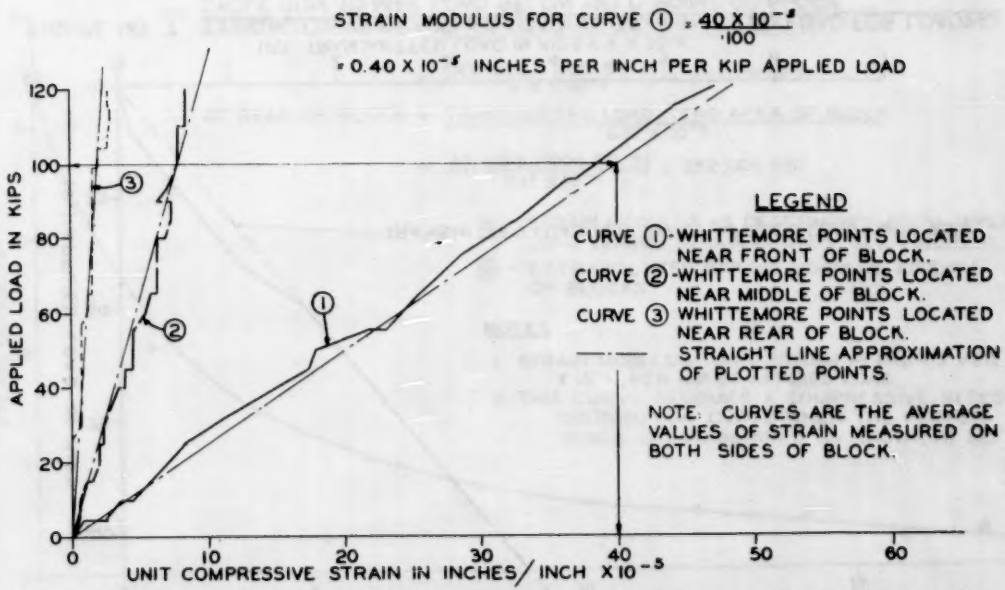


FIGURE NO. 6 = TYPICAL CURVES OF UNIT STRAIN VS APPLIED LOAD FOR THREE POINTS ALONG THE LENGTH OF TEST BLOCK FOR A LOADING CYCLE RUN TO A MAXIMUM LOAD BELOW THE YIELD POINT OF THE BLOCK.

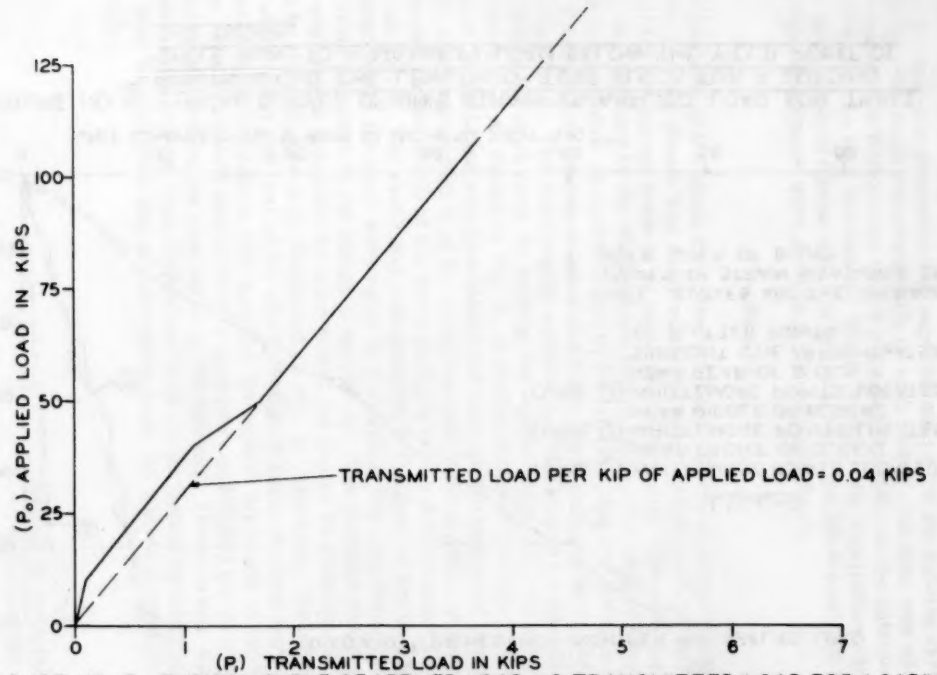


FIGURE NO. 7 TYPICAL CURVE OF APPLIED LOAD VS TRANSMITTED LOAD FOR LOADING CYCLE RUN TO MAX. LOAD BELOW YIELD POINT OF BLOCK

MODULUS OF CHALK IN HORIZONTAL COMPRESSION = $\frac{\text{UNIT STRESS}}{\text{UNIT STRAIN}}$

AT FRONT OF BLOCK = $\frac{\text{APPLIED LOAD / END AREA OF BLOCK}}{4.4 \times 10^{-6}}$

$= \frac{1000 \text{ LBS.} / 900 \text{ SQ. IN.}}{4.4 \times 10^{-6}} = 253{,}000 \text{ PSI.}$

AT REAR OF BLOCK = $\frac{\text{TRANSMITTED LOAD / END AREA OF BLOCK}}{0.17 \times 10^{-6}}$

$= \frac{40 \text{ LBS.} / 900 \text{ SQ. IN.}}{0.17 \times 10^{-6}} = 262{,}000 \text{ PSI}$

⊙ - STRAIN MODULUS AS DETERMINED FROM APPLIED LOAD VERSUS STRAIN CURVES, SEE FIGURE 11.

◎ - EXTRAPOLATED STRAIN MODULUS AT ENDS OF BLOCKS.

NOTES

1. STRAIN MODULUS UNIT STRAIN IN INCHES PER INCH $\times 10^{-6}$ PER KIP OF APPLIED LOAD.
2. THIS CURVE BECOMES A COMPRESSIVE STRESS DISTRIBUTION CURVE WHEN THE PROPER SCALE IS ESTABLISHED AS SHOWN AT LEFT.

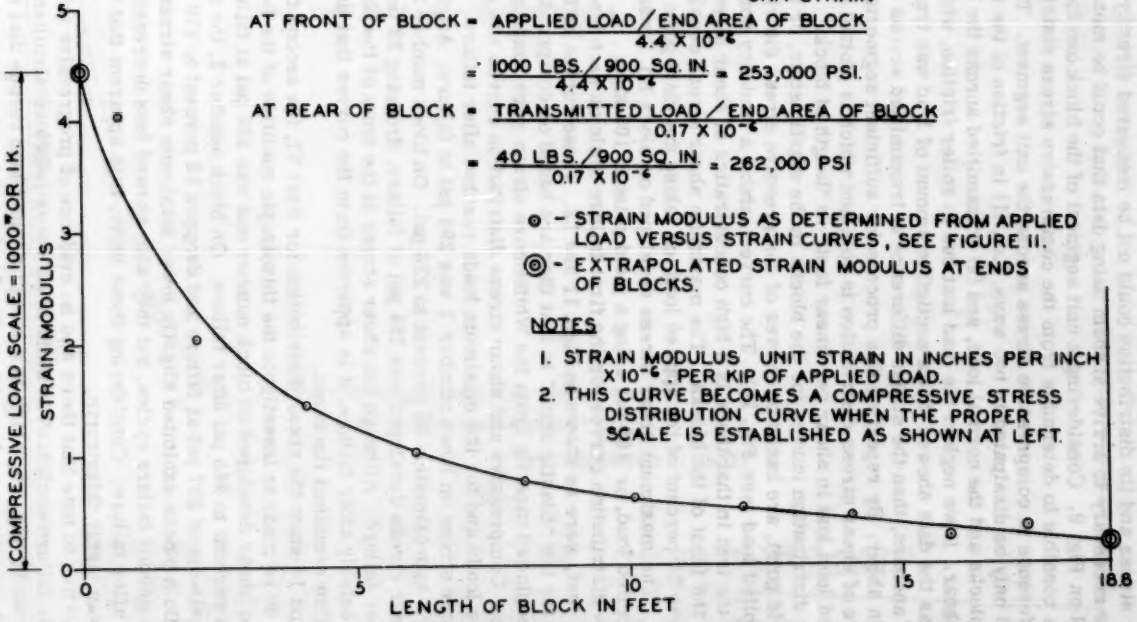


FIGURE NO. 8 TYPICAL COMPRESSIVE STRAIN DISTRIBUTION CURVE FOR A LOADING CYCLE IN THE "ELASTIC STATE"

It is noted that the field shear test resulted in values in the same range but slightly higher than those obtained from laboratory tests. This relationship is consistent with such other comparative data as are available.

The shear stress and its distribution could not be measured directly and it was therefore necessary to arrive at them using data that could be measured as illustrated on Fig. 9. Considering a unit segment of the block one foot in length, it was possible to determine from the compressive stress distribution curve the difference in compressive stress across the unit segment. This difference could only be dissipated in two ways, i.e., (1) in friction of the rollers between the blocks and the normal load, and (2) transmitted across the bentonite seam in shear. If we neglect the load lost due to roller friction, which is permissible as the data showed that a negligible amount of load was transmitted to the anchors, then the stress difference is transmitted across the bentonite seam in shear. By repeating this process for sufficient segments of the block, a curve of shear stress distribution is obtained which is plotted as "percent of applied load lost in shear per linear foot" vs "length of block."

The shear distribution curves for the blocks in the elastic state, or at loads below the yield point, are based on curves of compressive stress distribution per kip of applied load (see Fig. 10). The curves exhibit a tendency common to all phases of the test in that there is a high concentration of shear stress development at the front of the blocks. The maximum shear stress developed on block No. 1 was 54 percent of the applied load, or taking the yield point as 160 kips, 240 psi. The maximum shear stress developed on block No. 2 was 53 percent of the applied load, or 165 psi using a yield point of 105 kips.

The stress distribution curves for the first failure cycle on each block, Part V of the test, were as shown on Figs. 11 and 12. These curves differ from those plotted for the "Elastic state" in that they are based on compressive stress curves plotted directly from the Whittemore strain gage readings for specific loads. Compressive and shear stress distribution curves are plotted for the failure loads and for the maximum loads reached after failure. The maximum shear stress on block number 1 was 294 psi at failure. After failure, it dropped approximately 20 percent to 238 psi. On block number 2, the maximum shear stress developed was 224 psi at failure, dropping 33 percent to 149 psi after failure. Although the shear stress at the front of the block dropped appreciably after failure, it is apparent from the curves that the general distribution remained the same.

Figs. 13 and 14 show the shear distribution for Part VI, the second failure cycles which were made to investigate the thixotropic qualities of the bentonite. The maximum shear developed on block number one was 283 psi at failure, dropping 12.5 percent to 248 psi after failure. On block number 2, the shear reached a maximum of 207 psi at failure and dropped 18 percent to 170 psi after failure. Both blocks exhibited slightly lower maximum shear stresses at failure on the second failure cycles, but they also showed less decrease in shear stress after failure. Considering these tests, it is apparent that the bentonite seam was highly thixotropic.

It is interesting to note that there was no evidence of progressive failure in any of the four failure cycles. The dials in all cases indicated simultaneous failure as shown by Fig. 15, which is a plot of applied load versus dial movement for the first failure cycle on block No. 2. As can be seen from the curves, at 152 kips, all the dials spaced along the length of the block indicated an increased rate of movement, and at 184 kips all the dials again showed an increased rate. These curves are typical of the four failure cycles. The curves should not, however, be interpreted as indicating definitely that

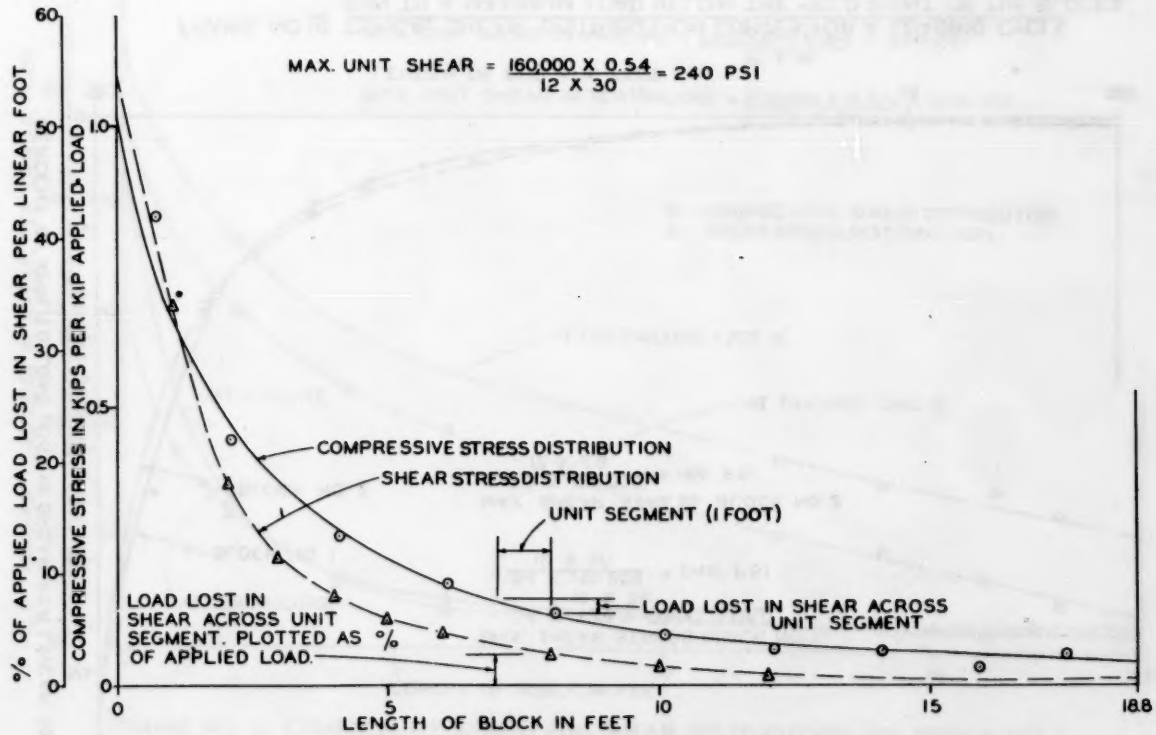


FIGURE NO. 9 METHOD OF OBTAINING SHEAR DISTRIBUTION

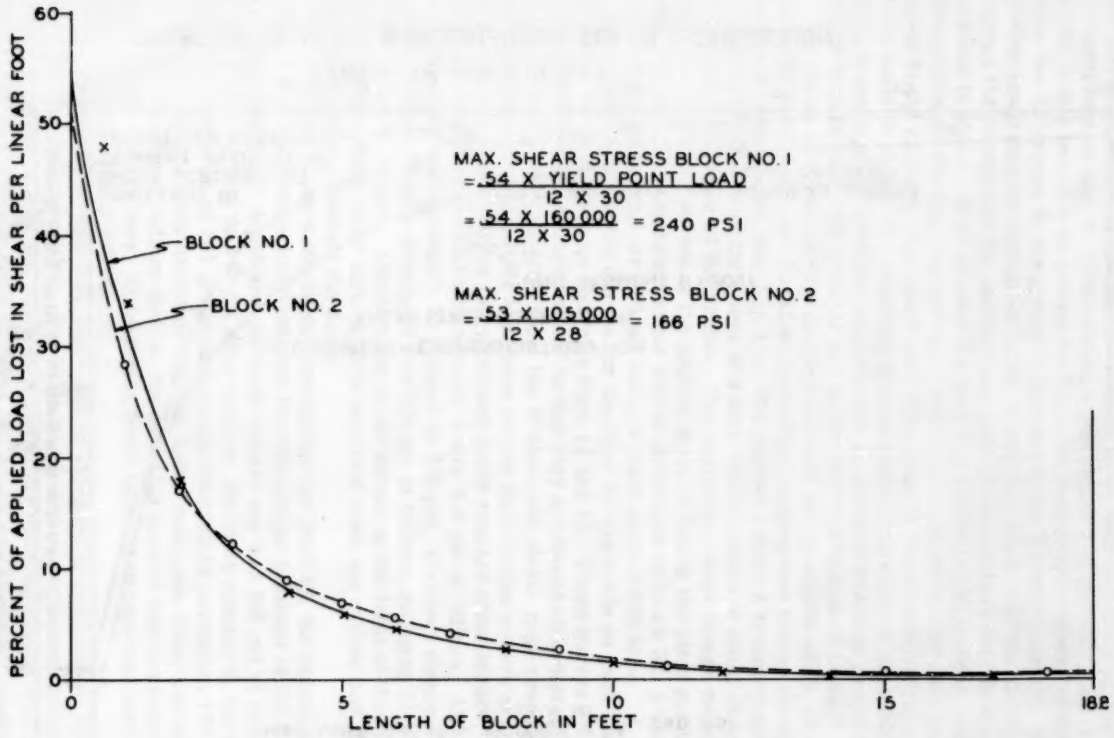


FIGURE NO. 10 TYPICAL SHEAR DISTRIBUTION CURVES FOR A LOADING CYCLE RUN TO A MAXIMUM LOAD BELOW THE YIELD POINT OF THE BLOCKS

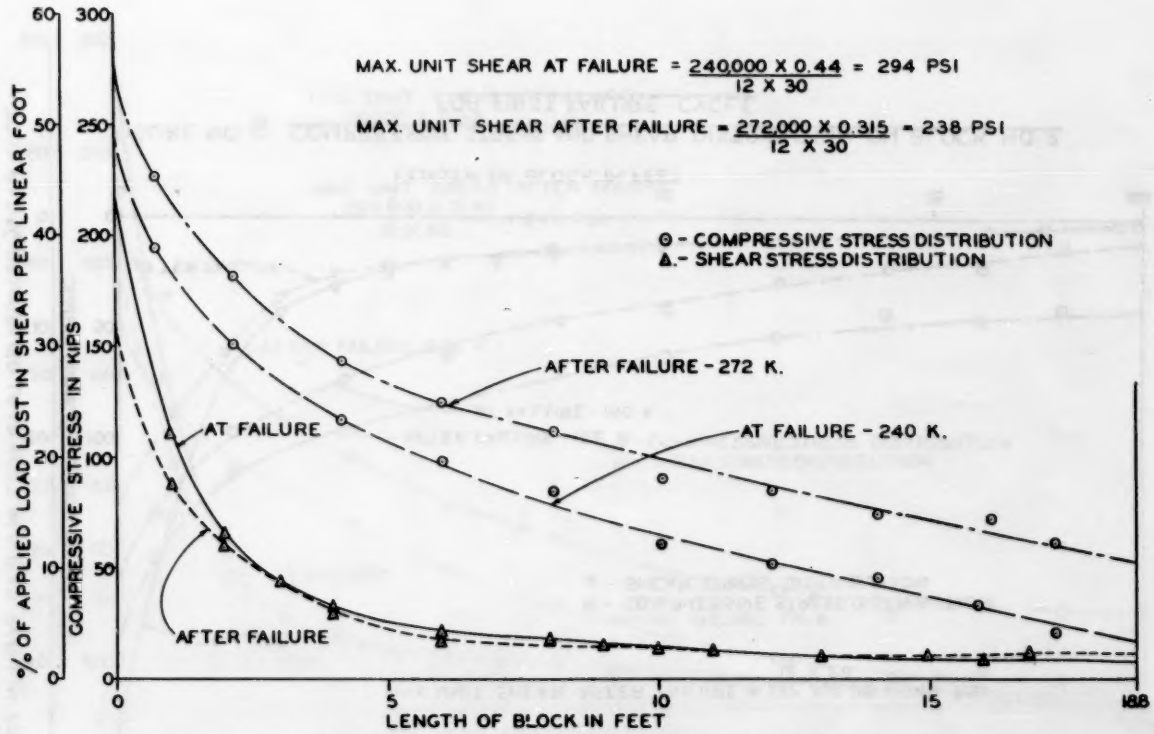


FIGURE NO. 11 COMPRESSIVE STRESS AND SHEAR DISTRIBUTION ON BLOCK NO. 1 FOR FIRST FAILURE CYCLE

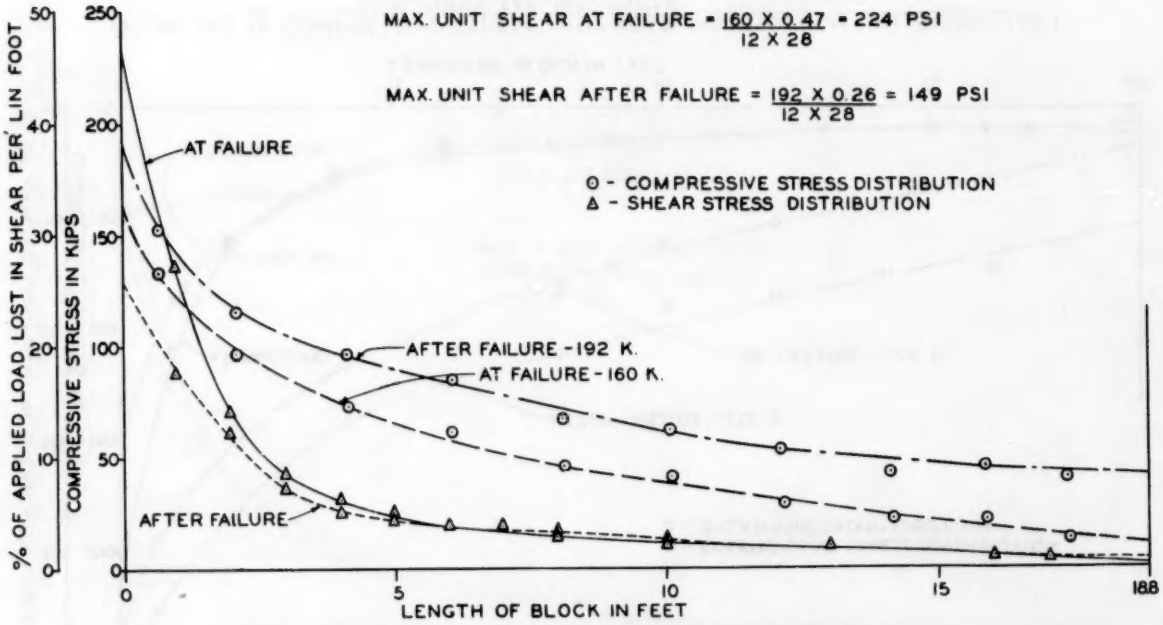


FIGURE NO. 12 COMPRESSIVE STRESS AND SHEAR DISTRIBUTION ON BLOCK NO. 2 FOR FIRST FAILURE CYCLE

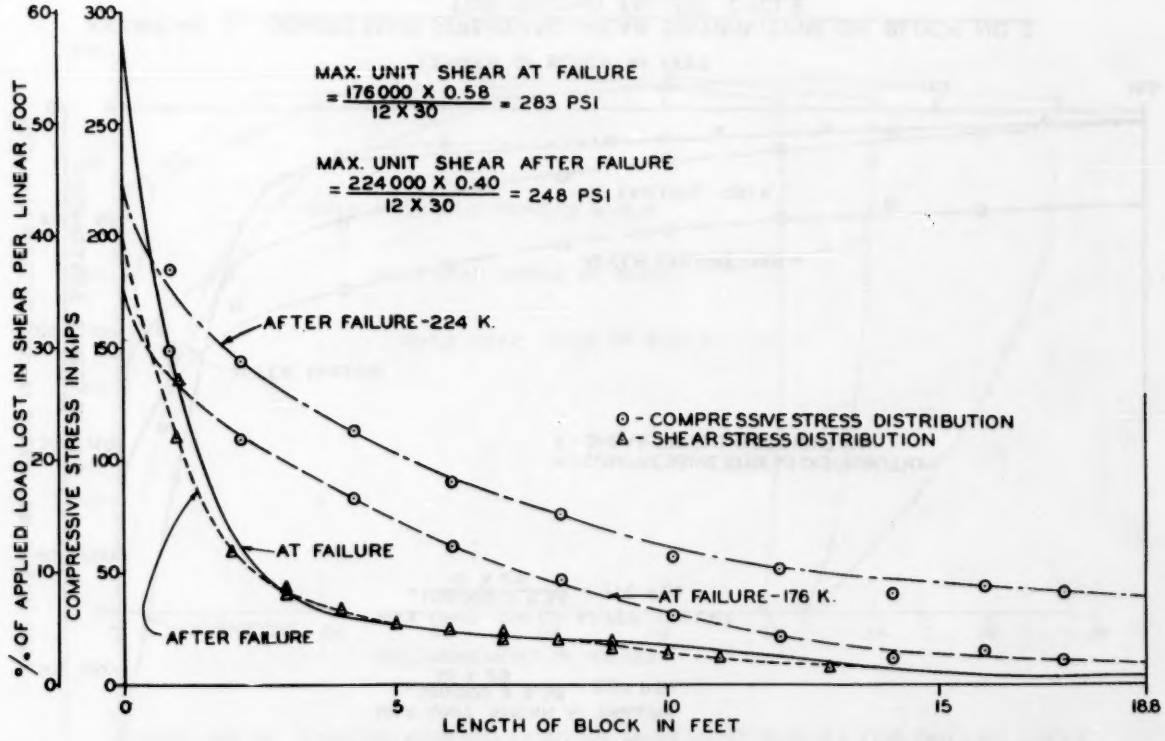


FIGURE NO. 13 COMPRESSIVE STRESS AND SHEAR DISTRIBUTION ON BLOCK NO. 1 FOR SECOND FAILURE CYCLE

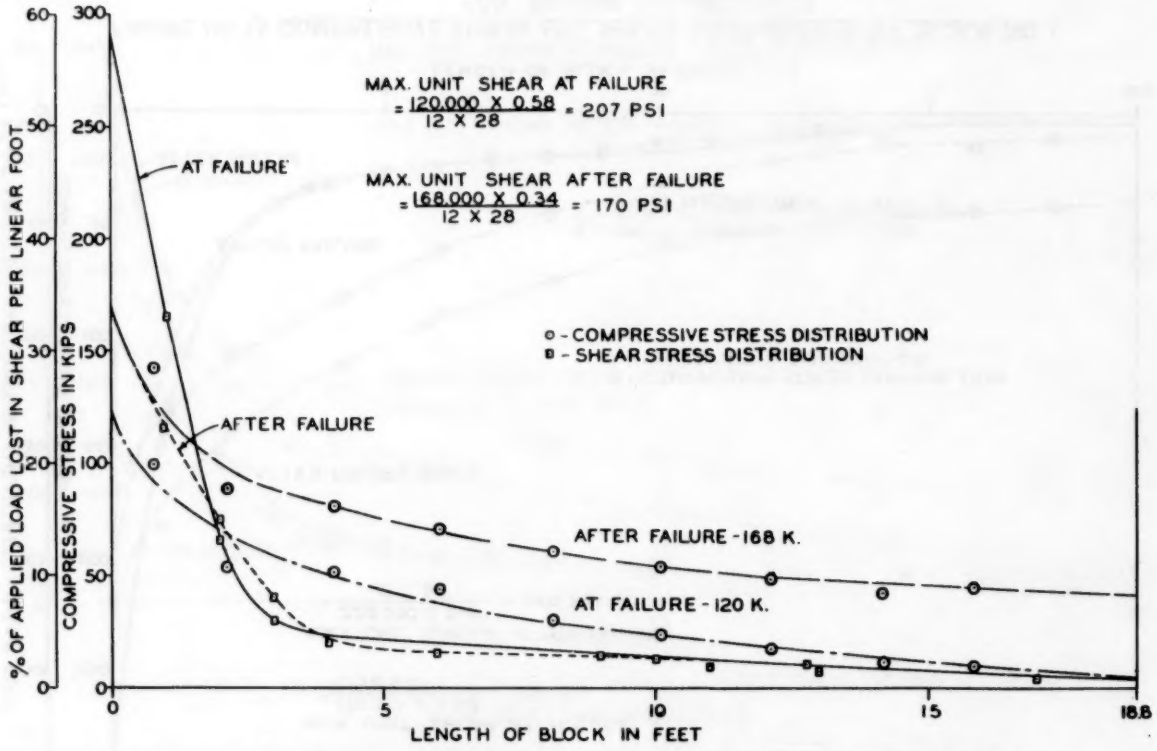


FIGURE NO. 14 COMPRESSIVE STRESS AND SHEAR DISTRIBUTION ON BLOCK NO. 2 FOR SECOND FAILURE CYCLE

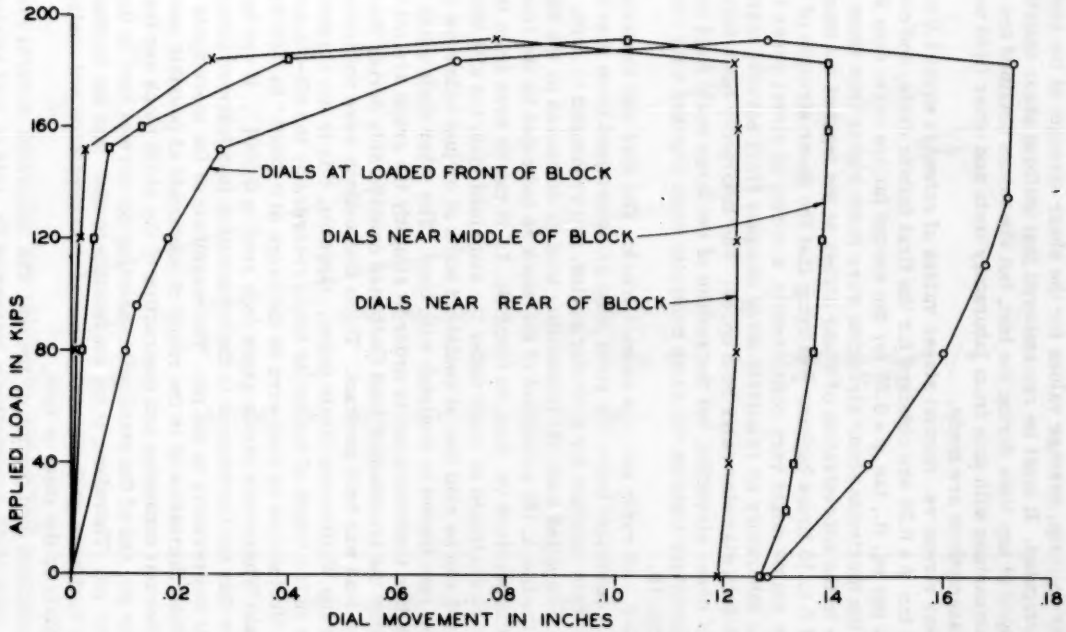


FIGURE NO. 15 TYPICAL APPLIED LOAD VS MOVEMENT CURVES FOR FAILURE CYCLE

progressive failure did not occur. It is entirely possible that it occurred rapidly and that if more sensitive measuring devices had been used and readings taken at closer intervals if not continuously, the results would have indicated as much.

Considering the two failure cycles and assuming that after failure the shear distribution was uniform, average values for the shear strength of the bentonite seam can be computed. It must be remembered that uniform shear distribution was not developed at any time during the test, but the values obtained are of interest for comparison with data from laboratory tests and other field tests, wherein like assumptions are made.

Plotting shear stress vs. normal stress values of cohesion equal 1.0 tons per sq. ft. and tan $\phi = 0.30$ are obtained for the first failure cycle, and cohesion = 0.95 ton per sq. ft., tan $\phi = 0.23$ for the second failure cycle (see Fig. 16). Actually the maximum shear strengths were much higher than those average values due to the concentration of shear stress at the front of the blocks, in the range of 8 to 10 times higher. Realizing that the shear strength of the many bentonite seams might vary considerably, a series of direct shear tests were run in the laboratory on relatively large samples from several seams obtained from 30-inch diameter calyx hole cores. The laboratory tests indicated a wide range of shear strengths, but the results of the large scale field shear test and the laboratory tests on the same bentonite seam checked very closely as shown on Fig. 16.

One sustained load cycle was run on each block. The load was increased by increments to a point just below the yield point as determined from previous loading cycles, held constant for a 10-day period, and rebounded to zero. Fig. 17 is a plot of (1) applied load, (2) transmittal load as measured by the SR-4's at the rear of the block, (3) movement of the block as indicated by the front dials, and (4) temperature vs. time on block No. 1. It can be seen from the figure that the block continued to move under the sustained load, but at a diminishing rate. Thus it can be said that at sustained loads at or just below the yield point, the creep rate tended to diminish with time. The other dials along the block exhibited like tendencies but in order to simplify the graph are not shown.

It is noted that the transmitted load fluctuated considerably during the time that the applied load was held constant. These fluctuations were not indicated by the dials or the Whittemore strain gages. However, this is not surprising as the changes in the length of the boiler tubes recorded by the SR-4's corresponding to the fluctuations in load were in the range of 0.00005" to 0.00015" and the dials and Whittemore strain gages only read to 0.0001". It can be seen from the figure that the fluctuations in the transmitted load followed closely those of the air temperature in the pit. The magnitude of the movements resulting in the load fluctuation is in the range of magnitude of possible movements due to thermal expansion and contraction of the chalk block and the chalk surrounding the pit, and of the steel rail connecting the normal load to the anchor outside the pit. Therefore, it seems feasible to say that the fluctuations in transmitted load were probably caused by thermal expansion and contraction of either the chalk or the steel or both.

After the sustained load portion of the test was completed, several cycles were made on each block progressively increasing the rate of load application. Figs. 18 and 19 are plots of applied load vs. the movement of the blocks as indicated by the dials located near the front of the blocks. The rate of load application was 5 kips per 40 minutes on the cycle III C on Block No. 1, 5 kips per 40 minutes up to 75 kips and then 10 kips per 40 minutes to a maximum load of 185 kips on the cycle IIIE, and 15 kips per 20 minutes to 185 kips on the cycle

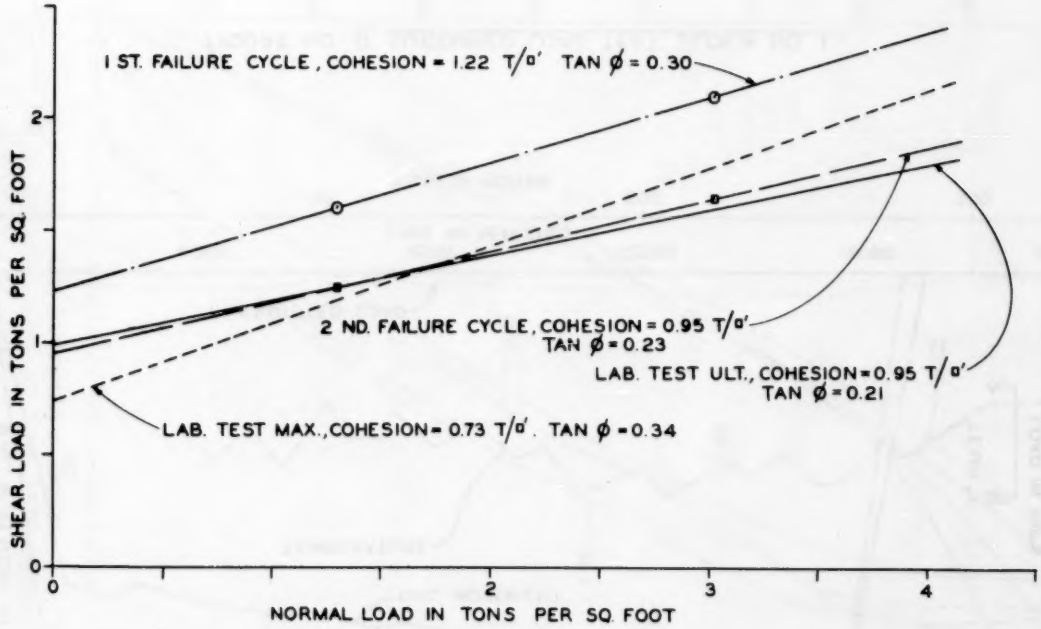

1 ST. FAILURE CYCLE, COHESION = 1.22 T/□' TAN ∅ = 0.30
2 ND. FAILURE CYCLE, COHESION = 0.95 T/□'
TAN ∅ = 0.23
LAB. TEST ULT., COHESION = 0.95 T/□'
TAN ∅ = 0.21
LAB. TEST MAX., COHESION = 0.73 T/□'. TAN ∅ = 0.34
SHEAR LOAD IN TONS PER SQ. FOOT
NORMAL LOAD IN TONS PER SQ. FOOT
0
1
2
3
4

FIGURE NO. 16 SHEAR STRENGTH ASSUMING UNIFORM DISTRIBUTION

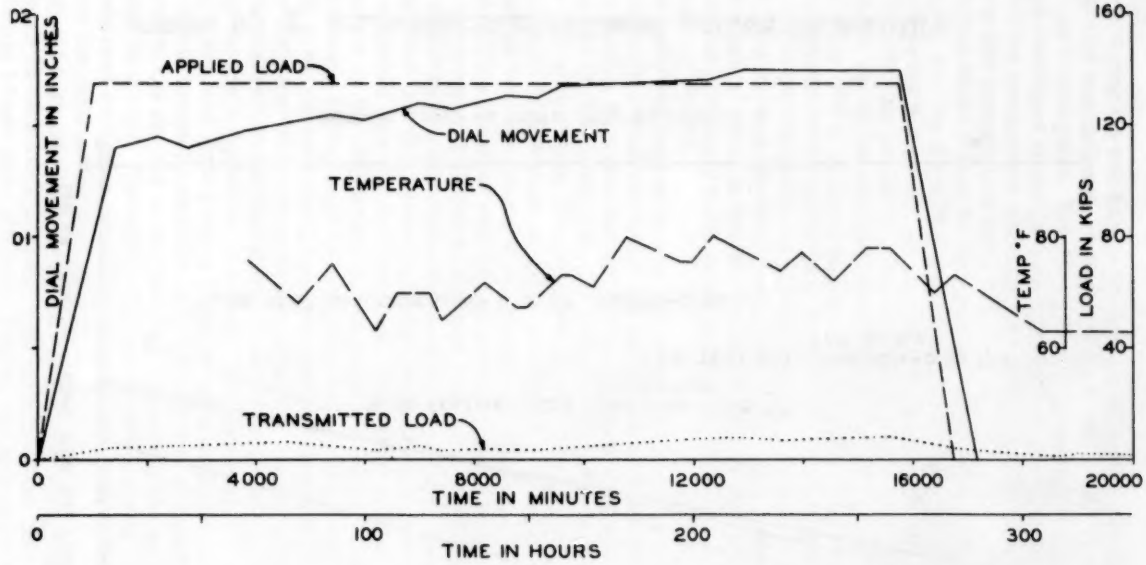


FIGURE NO. 17 SUSTAINED LOAD TEST BLOCK NO. 1

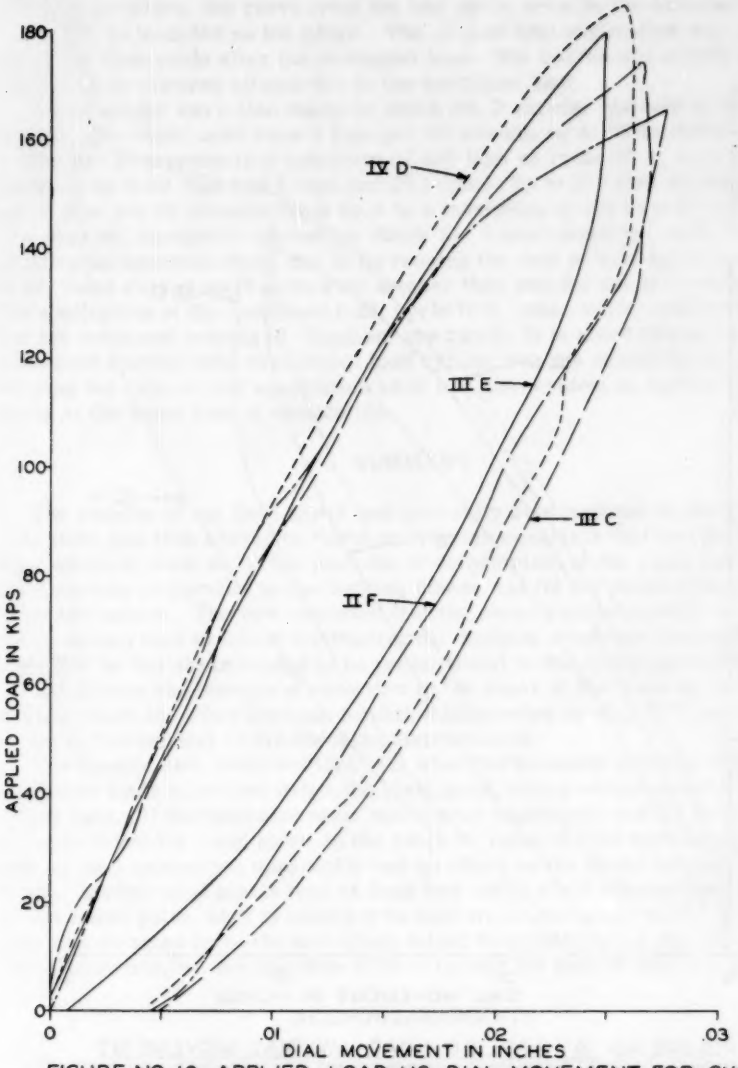


FIGURE NO. 18 APPLIED LOAD VS. DIAL MOVEMENT FOR CYCLES RUN ON BLOCK NO. 1 AT VARIOUS RATES OF LOAD APPLICATION

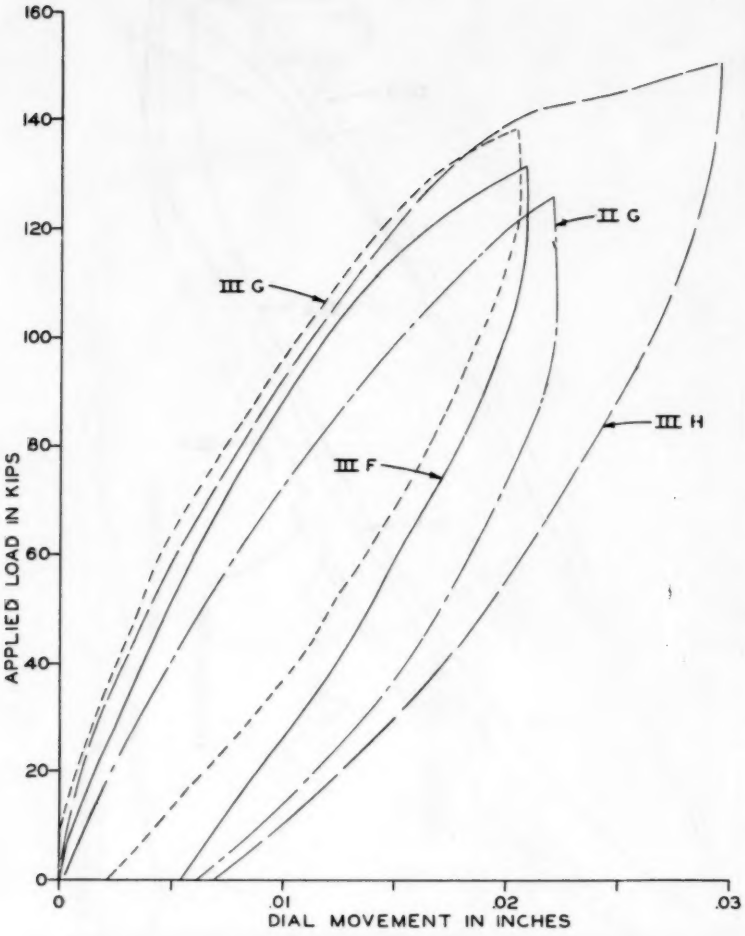


FIGURE NO. 19 APPLIED LOAD VS DIAL MOVEMENT FOR CYCLES RUN ON BLOCK NO. 2 AT VARIOUS RATES OF LOAD APPLICATION.

IV D. The load vs. movement curves for Block No. 1 were essentially identical, indicating that in the range of rates used, the rate of load application had no apparent effect on the shear characteristics of the bentonite seam. For comparative purposes, the curve from the last cycle prior to the sustained loading, cycle IIF, is included on the graph. The rate of load application was the same as on the first cycle after the sustained load. The curves are nearly identical indicating no adverse effects due to the sustained load.

Three cycles were also made on Block No. 2 varying the rate of load application. The rates used were 3 kips per 40 minutes up to 72 kips and thence at 6 kips per 20 minutes to a maximum of 132 kips on cycle III F; 3 kips per 40 minutes up to 42 kips and 6 kips per 20 minutes up to 110 kips on cycle III G, and 6 kips per 20 minutes from zero to a maximum of 150 kips on cycle III H. The load vs. movement curves for Block No. 2 were much the same, again indicating no apparent effect due to increasing the rate of load application. However, these curves were somewhat steeper than that for the last cycle prior to the application of the sustained load, cycle II G, which might indicate a tendency for the sustained loading to "toughen" the block. It is noted that the yield point increased slightly with successive load cycles, but this cannot be attributed to varying the rate of load application as it was also evident in earlier cycles made at the same rate of application.

SUMMARY

The results of the field shear test generally substantiated those of laboratory tests and thus served to "firm up" design constants that had previously been adopted, such as (a) the modulus of deformation of the chalk in a horizontal direction or parallel to the bedding planes and (b) the shear strength of the bentonite seams. The test indicated that the shear characteristics of the bentonite seams tend to follow the theoretical limiting condition illustrated by Fig. 2(B) as the shear tended to be proportional to the shearing displacement before failure and, despite a reduction in the shear at the front of the block, did not reach the other limiting condition illustrated by Fig. 2(C), wherein the shear is independent of the shearing displacement.

The results also indicated that: (1) when the bentonite seam is subjected to sustained loads at or just below the yield point, creep occurred but at a diminishing rate, (2) the bentonite seam was highly thixotropic and (3) when subjected to loads below the yield point, in the range of rates of load application used, the rate of load application apparently had no effect on the shear strength of the seam. A controlled strain type of field test might yield interesting information on the latter point, as it is contrary to data from laboratory tests. A mass of data was obtained from the test which might be of interest on the above and other questions, but for the sake of brevity only the salient data are presented.

ACKNOWLEDGMENTS

The test was designed and the apparatus developed by P. T. Bennett, Member ASCE, in the Omaha District Office, Corps of Engineers, under Col. H. J. Hoeffer, CE, District Engineer. J. O. Ackerman, Assoc. Member ASCE, is Chief of the Engineering Division and E. Soucek, Member ASCE, is Chief of the Design Branch. Personnel of the Fort Randall Area Office, Corps of Engineers carried out the test under the general supervision of Mr. G. O. Evans, Area Engineer, and Mr. J. A. Trantina, Chief of the Engineering Division.

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a. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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